Integrated Watershed Management using RS and GIS: A Case Study of Megech Watershed, Blue Nile Basin, Northwest Ethiopia

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CHAPTER ONE

1.1 Introduction:

A watershed is a catchment or drainage basin, a widely accepted scale for water governance activities (Arfasa, 2019; Cohen and Davidson, 2011; Menon, 2007). It's a topographically demarcated area drained by a stream system to a point in the stream (Narendra et al., 2021). Watersheds are landscape units that are spatially explicit and feature a variety of interconnected physical, ecological, and social aspects (Neachell, 2014). It's also a geographical area where humans use and manage the area's resources, such as soil, water, vegetation, crops, native vegetation, and wildlife, including domestic and wild animals (Wani et al., 2011).

Watershed management is the integrated use of land, vegetation, and water in a geographically discrete drainage area to benefit its residents and protect or conserve hydrologic services (Darghouth et al., 2008). Watershed management has become increasingly important to improve people's livelihood while preserving and regenerating their natural resources.

Integrated watershed management is defined as managing a watershed system with sustainable technological options, which ensures the sustainability of the land, agriculture, and forestry practices and will conserve natural resources while allowing adequate institutional and economical options (Lee and Chung, 2007). The idea implies the integration of different disciplines, such as technical, social, and institutional dimensions of the watershed, through an inclusive decision-making process to manage the protection, conservation, and restoration of resources in the watershed (German et al., 2007).

Integrated watershed management provides an excellent opportunity to work land and water resources in an integrated manner for sustainable livelihoods while protecting the environment is also a key to sustainable development (Sahrawat, 2011). Integrated watershed management considers the natural resource, technology use, institution, and economic aspects or dimensions together. Its implementation reduces soil erosion, increase water availability, increase productivity, access to information, indigenous technology which are locally suitable, dissemination, public participation, property right, land tenure, and ownership and governance (Vishnudas and Savenije, 2005).

The application of geospatial spatial technology, such as remote sensing and geographic information, for spatial mapping has paramount significance. Using existing satellite and

topographic data can improve existing land surface information. Investigating terrain features' geographical extent and spatial distribution employ digital elevation models (DEMs) as input data (Yamazaki et al., 2017). Researchers, resource planners, and policymakers are increasingly aware of GIS's potency and unique ability to improve watershed management by analyzing and mapping the geographic terrain (Tim, 2003). Land use planning and the necessary supporting data are critical for developing countries that are usually under extreme environmental and demographic pressures. Natural resource variability mapping approaches and methods are essential for adequately guiding spatial planning (Bocco et al., 2001).

Any digital mapping using existing topographic data is possible and, depending on the study size should improve existing surface information (Garca et al., 2017). Mapping and analyzing the terrain, geomorphic context, and vegetation can help diagnose and select the best management or restoration choices for natural resources and predict the success of rehabilitation methods (Lord, 2009). A detailed geomorphological or landform map for environmental management practice is still lacking (Maerker et al., 2019). Even within a single area, differing degrees of land degradation may occur. Land management will be particularly successful in places where decision-making processes at various levels of society prioritize implementing soil and water conservation and other forms of land rehabilitation in situ and at the catchment level (Nyssen et al., 2009). Terrain analysis includes using a Digital Elevation Model and other satellite data to model the landscape. It provides quantitative results and models the actual landscape processes accurately.

In the highlands of Ethiopia, commonly northern and northwest Ethiopia, land degradation is severe due to water-induced soil erosion. Mass mobilization for restoration via soil and water conservation practices did not stop the threat (Meshesha and Tripathi, 2016). Since 2008, the government has been implementing sustainable land management initiatives in several sections of the country to address this issue (Negasa, 2020). Even though sustainable land management is a top policy priority in Ethiopia, adopting and applying sustainable land management techniques are still low (Ewunetu et al., 2021). Improper plowing methods, inadequate technology, and cultivation mechanisms increase the risk of water-induced soil erosion in Northwest Ethiopia. Runoff during the rainy seasons quickly degrades, transports, and removes the loam soil from the area (Zerihun et al., 2018).

In the lower part of the Megech watershed, the terrain is gradually deteriorating due to natural and human-caused deforestation, which causes significant soil erosion in mountainous regions and deposition throughout the plains (Teshome, 2016). Uncontrolled deforestation for fuel and construction purposes has pushed soil degradation even more. As a result, topsoil has been removed from farmed regions, resulting in occasional decreases in agricultural production (Teshome, 2016). Some research works that focused only on the dam area of the Megech watershed reported that around 47 percent of the dam area is susceptible to erosion, resulting in substantial sediment yields that surpass the acceptance level. Approximately 18% of the dam area has a high risk of soil erosion, resulting in yearly sediment yields higher than the dam catchment's average (Abdi, 2016). BCEOM (1998) anticipated a mean twelve-monthly residue load of 240,000 tons (576 tons/km^2/yr) for the Megech block location, an area with low forest cover. WWDSE (2008) assessed the Megech tank residue output of 1,170 tons/km^2/year in another study. Therefore, the previous studies in this region focused on some environmental problems and concentrated on the Megech dam site, which has been under construction for irrigation purposes. In addition to the dam area of the watershed, mapping and analyzing the entire watershed's natural resources and assessing farmers' perception and participation in watershed management in an integrated approach would give complete information for sustainable management of the watershed.

1.2 The objectives of the study:

The main objective of integrated watershed management using RS and GIS is to provide data for the proper management of natural resources of the Megech watershed in an integrated manner involving the local community for sustainable development and utilization by addressing the following specific objectives:

1. Analysis of morphometric drainage characteristics of the watershed.
2. Terrain mapping and analysis for land management.
3. Assessment of the extent of soil erosion using the RUSLE model.
4. Investigation of Land use\land cover changes from 1986 to 2020 using satellite images.
5. Assessment of farmers' perception of watershed degradation, participation in watershed management, and factors affecting management measures.

CHAPTER TWO

2.1 Methods and techniques:

2.2 Location of the watershed studied:

Megech river sub-basin is one of the significant subbasins of Lake Tana in Ethiopia's Upper Blue Nile basin (Asitatikie and Gebeyehu, 2020). It rises from the Lay Armachiho and Gondar City highlands and has a catchment area of about 1309.56 km^2. The catchment elevation ranges between 1755–2985 m above sea level. Megech river is found between 12°20′ 39″ N to 12°40′ 39″ N latitudes and 37°10′ 30″ E to 37°31′30″ E longitudes. Megech river originates from the Layarmachiho and Wogera highlands and flows southward, crossing the Gondar Zuria and Dembia floodplain into Lake Tana. The watershed area is densely populated (CSA, 2007). The farmers have used the catchment for traditional irrigation agriculture for long years. The upstream of the watershed is steep and mountainous (Abdi et al., 2016).

The watershed's highest elevation is 2,985 m above mean sea level in its northeastern part. The mean annual precipitation is about 1,050 mm, with 1,100 mm in the upper part and approximately 1,000 mm in the lower leg. Temperature varies from 11.5°C to 30°C. Maximum temperatures vary from 23°C in July to 30°C in March, whereas minimum temperatures range from 11.5°C in January to 15.6°C in April and May. Humidity varies between 39% in March and 79% in August. Wind speed is low, thus minimizing potential evapotranspiration values between 101 mm/month in July and 149 mm/month in March (WWDSE, 2008). Most of the watershed's major landform features appear flat, undulating, rolling, hilly, mountainous, wedge-shaped, and steep-sloped (FAO, 2002).

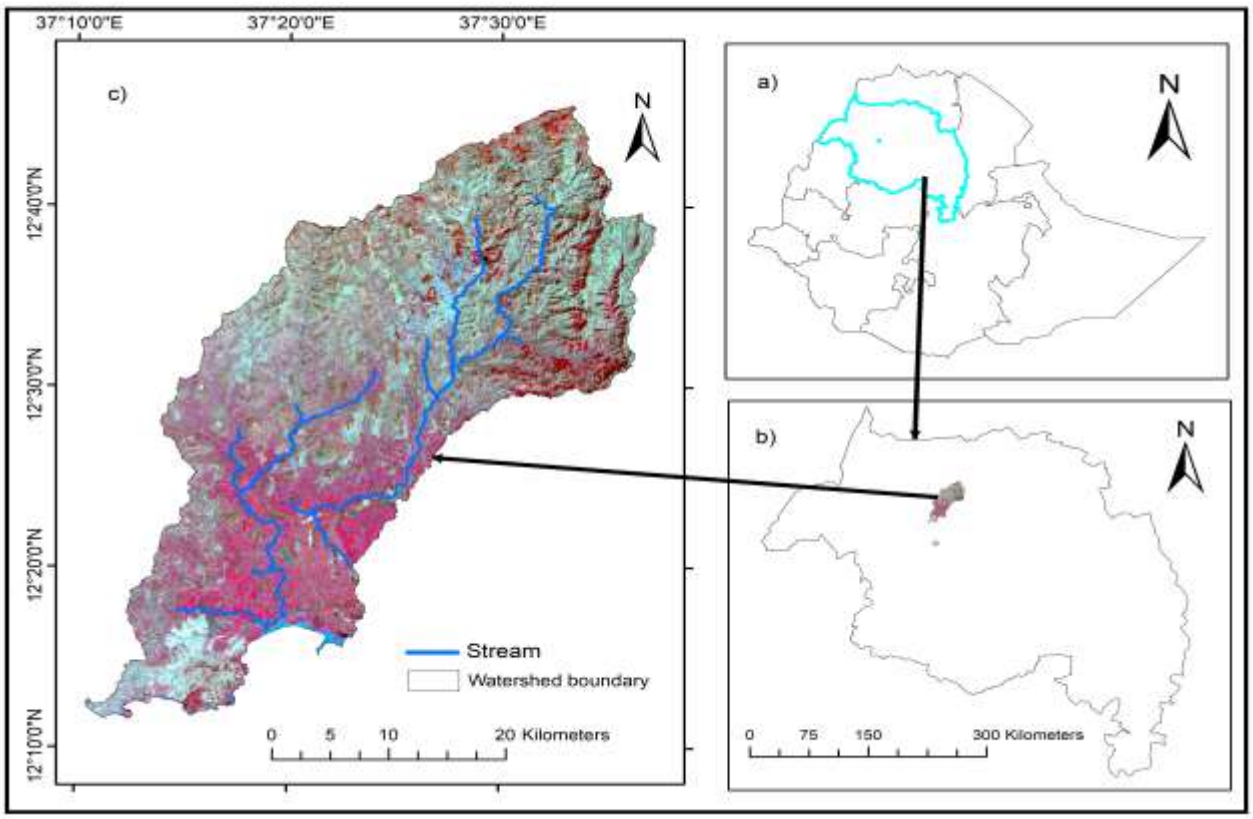

Fig. 1: Location of the study watershed, Megech (c), Northwest Ethiopia (b), and Ethiopia (a).

2.3 Data types and sources:

The data types used are satellite images of TM 1986, TM 1996, TM 2008, and OLI 2020 downloaded from the United States Geological Survey database (USGS). ASTER DEM was also used to delineate the watershed and analyze morphometrics and terrain. Soil data was downloaded from the FAO soil database. Rainfall data, used for the RUSLE model to quantify soil erosion in the watershed, were collected from the national meteorological agency of Ethiopia, Addis Ababa. The household survey was also done among the Megech watershed farmers using a survey questionnaire. Continuous field observation took place. To get preliminary information about the watershed's LULC type and degradation vulnerability.

2.4 Data analysis:

ERDAS IMAGINE 2014 and ArcGIS 10.4 software were used to classify satellite images for the land use\land cover change study. A maximum likelihood supervised image classification method was employed. ArcGIS 10.4 was used to perform the morphometric and terrain analyses. SPSS version 23 and a Microsoft Excel spreadsheet were used to evaluate the survey data gathered through questionnaires about farmers' perception of watershed degradation and participation in conservation works and to identify factors related to farmers' implementation of watershed management.

CHAPTER THREE

1.3 Terrain mapping and analysis for land management: the case of Megech watershed of the Blue Nile basin, northwest Ethiopia:

Digital mapping using existing topographic data is possible, and depending on the study size, it can improve existing land surface information. For the Megech watershed, both the primary and secondary terrain attributes are mapped and analyzed. This study's topography of the Mgech watershed mapping and analysis has been done. The data inputs were a digital elevation model and satellite images of 30 meters resolution. The soil data collected were from Food and Agricultural Organization. The method we used to calculate the various topographic features was based on geometry and elevation calculations from DEM and satellite images. ArcGIS 10.4 software was used to map and analyze the Megech watershed terrain

The prominent landform of the Megech watershed is low mountains (31.53%), irregular plains (28.18%), smooth plains, flat landforms (19.16%), and breaks (14.86%). The slope classes are 0–10 degrees (62.65%), gentle slope, 15 25 degrees (25.19%), moderate slope, and>45 degrees steep slope covering 4.14% of the watershed. The north, northwest, and northeast are the most vertical terrain, greater than 45 degrees, reaching 75 degrees and showing very steep terrain.

The geological elements include basalt, marsh soils, alluvium, and colluvium. The terrain wetness index of 5.71 occurs in locations with more extensive upslope areas drained to a gentler slope of the watershed near Lake Tana. The topographic ruggedness index results indicate that the southern portion of the watershed is nearly level. In contrast, the northern and northeastern parts are rugged terrain, which could be susceptible to soil erosion. Based on stream power index analysis, the upper part of the Megech watershed, especially the north and northwest parts, is the source of many streams flowing to the south where erosion could occur. Around 9.72 km^2 area is under the shallow soil depth of 0-25 cm, whereas about 608.32 km^2 area is between 25-100 cm and 564.99 km^2 area of land is from 100 -150 cm depth, which is a blessing to maintain soil fertility and boost agricultural productivity. Eutric Leptosols (46.45%), Eutric Vertisols

(44.03%), and Chromic Luvisols (7.75%) were significant soil types. Clay soils cover 57.83% and clay to clay loam 41.43%, which are the important textures.

Compound topographic index, soil types, texture, depth, and erosion extent were mapped and analyzed. Finally, the water from the upper watershed may flood risk to the lower part of the watershed, where a dense population is found near the Lake Tana area. This study would support local planners of natural resources for development and management decision-making. The moderate and severe soil eroded part of the watershed needs serious and urgent soil and water conservation practices such as terracing or stone bund construction, checking the dam structure, covering the land with a plantation, and applying area closure for degraded land rehabilitation.

CHAPTER FOUR

4.1 Geospatial technology approach on drainage morphometry analysis of Megech watershed and: implications for the conservation of soil and water of the Blue Nile, northwest Ethiopia:

Morphometric analysis, which includes calculating the landscape's quantitative attributes, is an integral part of the watershed classification. A watershed's morphometric study research assists in understanding the relationship between operating processes and landform characteristics. Quantitative morphometric analysis was carried out for Megech, the Blue Nile, by estimating (1) linear aspects, (2) aerial elements, and (3) relief aspects. An effort has been undertaken to measure the morphometric properties of the Megech watershed. ASTER DEM has been used as input data for extracting morphometric parameters. The drainage networks were divided into groups using morphometric analysis and Strahler's categorization scheme. The software ArcMap 10.4 with ArcGIS extension was used to analyze the data.

The digital elevation model analysis indicates that the watershed has a surface area of 1309.56 km^2. As calculated from elongation, circularity, and form factors, the shape of the watersheds reveals the elongated shape and the dendritic pattern. The Megech sub-watershed includes a third-order stream (Fig. 2). Lower stream orders, in particular first-order streams, dominate the sub-watersheds (Fig. 2). The length of overland flow has a higher value (1.06) for Megech, indicating low relief.

The drainage density of the study watershed was morphometrically analyzed and obtained at 0.47 km/km^2 for the Megech sub-basin. This value indicates the basin is highly absorbent and results in better underground water storage capacity sub-basin, meaning very coarse channels.

The ruggedness number for the Megech sub-basin was 0.56, showing moderate and long, rugged topography, which could be susceptible to flash floods and soil erosion. The dissection index values for Megech 0.40 show river sub-basin is moderately dissected. The ruggedness number is 0.56 implies moderate soil erosion probability. The findings of this study include drainage morphometry data to understand watershed characteristics better and serve as a

framework for better planning, management, and decision-making to ensure the long-term use of water and soil watershed resources. It is recommended that soil and water conservation work in the watershed is required to reduce soil erosion by runoff.

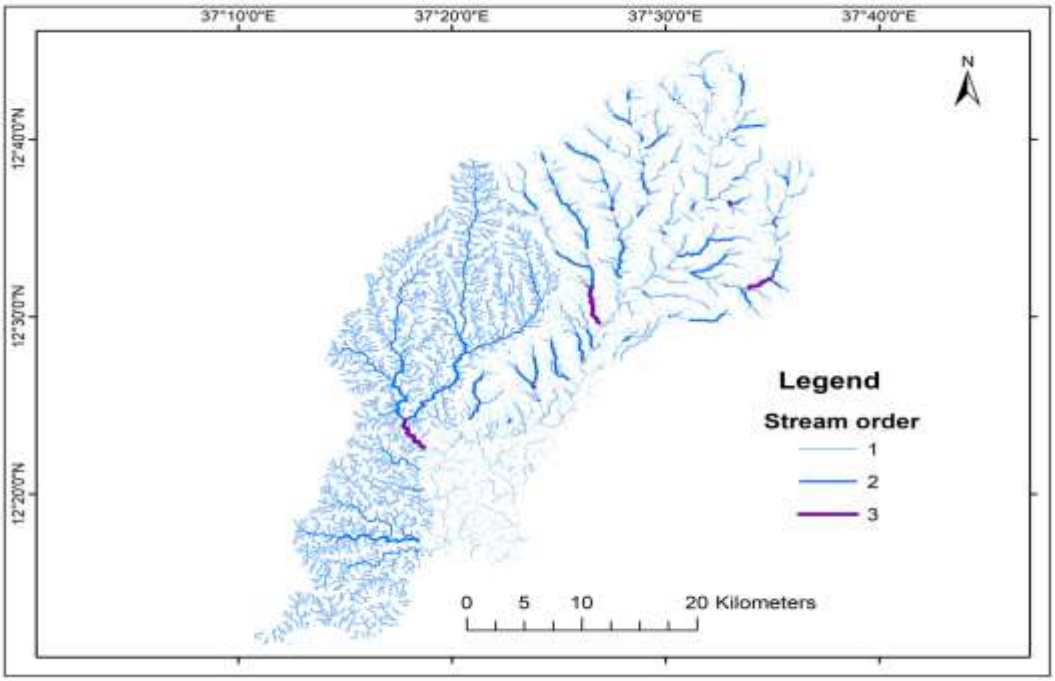

Fig. 2: Megech River stream order.

CHAPTER FIVE

5.1 Assessment of soil erosion extent using RUSLE model integrated with GIS and RS: The case of Megech watershed, northwest Ethiopia:

Soil erosion valuation at a spatial scale is crucial for assessing natural resource quality in a farming country like Ethiopia. The study's goal was to determine the rate of soil erosion in the Megech catchment in Northwest Ethiopia using the Revised Universal Soil Loss Equation (RUSLE) model aggregation with geographic information system and remote sensing. Sediment yield and transport were also estimated using the sediment delivery ratio.

Precipitation data (R-value), soil data (K value), land cover data from satellite pictures for the (C and P values), and topographical data from a Digital Elevation Model (DEM) for the LS component made up the data inputs for the Revised Universal Soil Loss Equation (RUSLE) model. It was completed using the ArcGIS 10.4 software. The mean annual soil loss is 110.60 t ha^{-1} yr^{-1}. Each year, a total of 8499.74 t $h^{-1}yr^{-1}$ of soil eroded. On average resulting in 1605.30 t/km^2/year, sediment material has been transported to the stream channels and deposited with a sediment delivery ratio of 1.87. The strength of soil erosion in the area is divided into six categories (Table 1 and Fig. 3). The erosion rate classes were 46.38 percent (0-12 t ha^{-1} yr^{-1}) low, 13.63 percent (12-20 ha^{-1} yr^{-1}) moderate, 9.22 percent (20-35 ha^{-1} yr^{-1}) high, 12.30 percent (35-50 ha^{-1} yr^{-1}) very high, 7.20 percent (50 up to 100 ha^{-1} yr^{-1}) sever, and 11.27 percent (>100 ha^{-1} yr^{-1}) very severe erosion.

According to erosion severity, 46.38 percent of the watershed is at low soil erosion. In comparison, 11.27 percent is at risk of highly severe erosion (Table 1 and Fig. 3). The north and northeastern sections of the watershed have a moderate to highly extreme erosion risk due to steep slopes, high rainfall, and weak conservation measures. The severely eroded parts of the plateau and vertical portions need to be covered by plantation, stone bund, and check dam constructions.

Table 1: Potential soil erosion rate of Megech watershed

Class	Soil loss (t $ha^{-1}yr^{-1}$)	Area (ha)	Percentage area	Severity class
1	0-12	58828	46.38	Low
2	12-20	17288	13.63	Moderate
3	20-35	11696	9.22	High
4	35-50	15648	12.30	Very high
5	50-100	9080	7.20	Sever
6	>100	14296	11.27	Very severe

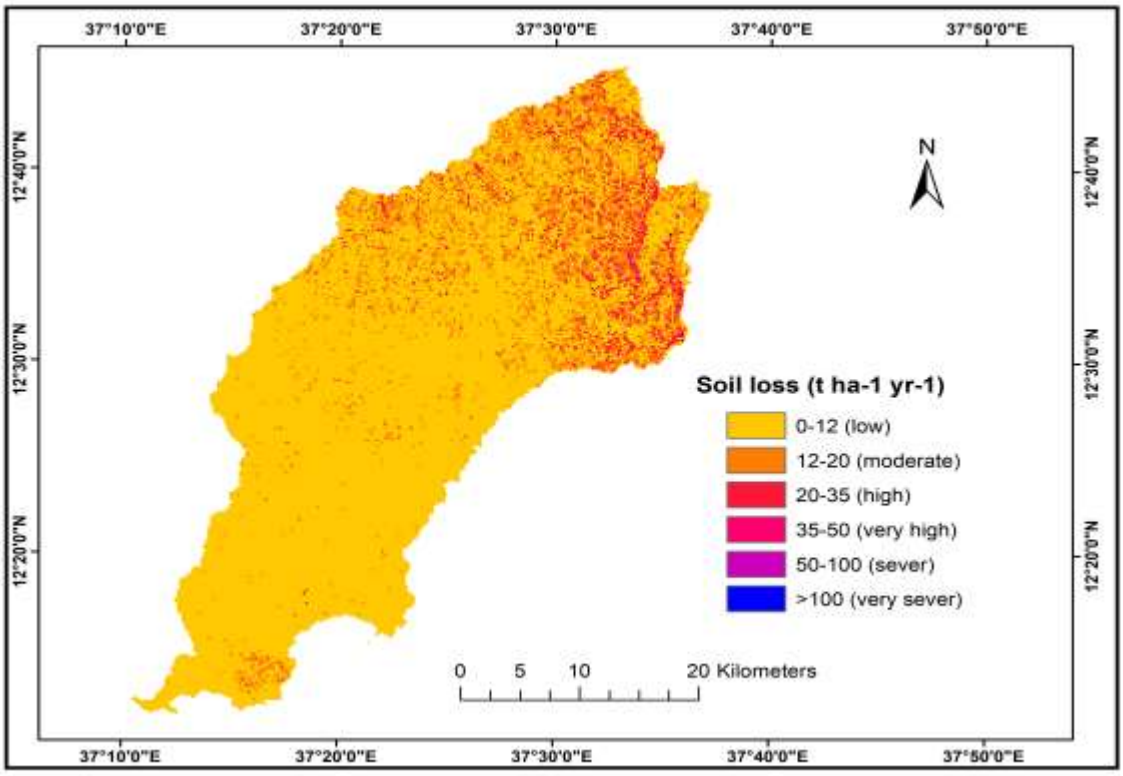

Fig. 3: Soil erosion severity class map

CHAPTER SIX

6.1 Investigation of land use\land cover change and potential drivers: the case of Megech watershed, Blue Nile basin, northwest Ethiopia:

Land is a vital natural resource with enormous economic, social, and biophysical uses for a less developed country like Ethiopia, where more than 80% of the population depends on subsistence agriculture. The Megech watershed land use\land cover change was studied using satellite images of TM 1986, TM 1996, TM 2008, and OLI 2020 accessed from the United States Geological Survey (Fig. 4). The satellite images were pre-processed and classified using ERDAS Imagine 2014 and ArcGIS 10.4. The Kappa statistics percentage for image classification accuracy were 86.80%, 80%, 88%, and 89% for 1986, 1996, 2008, and 2020 respectively. A Household survey of 371 samples was applied using a random sampling technique to study the drives of land use\land cover change.

The analysis showed that forest land change was 2.09% from 1986 to 1996. From 1986 to 2020, it changed and declined by -4.68%, with a continuous decreasing trend in the study area from 1986 to 2020. The shrubland has changed by 13.93% from 1986 to 1996; from 1996 to 2020, it increased by 0.96%. From 2008 up to 2020, it decreased by -1.92%. Generally, from 1986 to 2020, it was altered by 12.90%, indicating an increase. The cultivation land increased and expanded from 1996 up to 2020. The built-up area changed continuously from 1986 to 1996 by 0.44% (Table 2 and Fig. 4).

The change from 1986 to 2020 reached 2.23%, indicating the expansion of the urban regions and settlements in the study area (Fig. 4). The water body covers less extent in the watershed. However, it increased by 0.08% from 1986 to 1996 and reached 0.23% in 2020 (Table 2 and Fig. 4). Thus, land use\land cover has constantly been changing, primarily due to social advancement and natural factors. A suitable participatory urban and rural land use approach needs to be developed to lessen the effects of urban expansion on other land use types. Intensifying afforestation programs are required to replace vanished vegetation by focusing on indigenous and long-lasting forest types to substitute the degraded land.

Table 2: Area and percentage of land use/cover classes from 1986 and 2020

	1986		1996		2008		2020	
LULU	Area ha	% [a]	Area ha	% [a]	Area ha	% [a]	Area ha	% [a]
Forest land	7288.11	5.57	10034.5	7.66	2035.3	1.55	1170.3	0.89
Shrub \ grassland	10291.75	7.85	28425.1	21.71	29685.2	22.67	27170.8	20.75
Cultivation land	113019.06	86.30	91446.3	69.83	96762.8	73.89	99032.2	75.62
Waterbody	112.31	0.09	217.4	0.17	145.0	00.11	416.5	0.32
Built up	246.64	0.19	834.6	0.63	2329.7	01.8	3168.14	2.42
Total	130957.9	100	130957.9	100	130957.9	100	130957.9	100

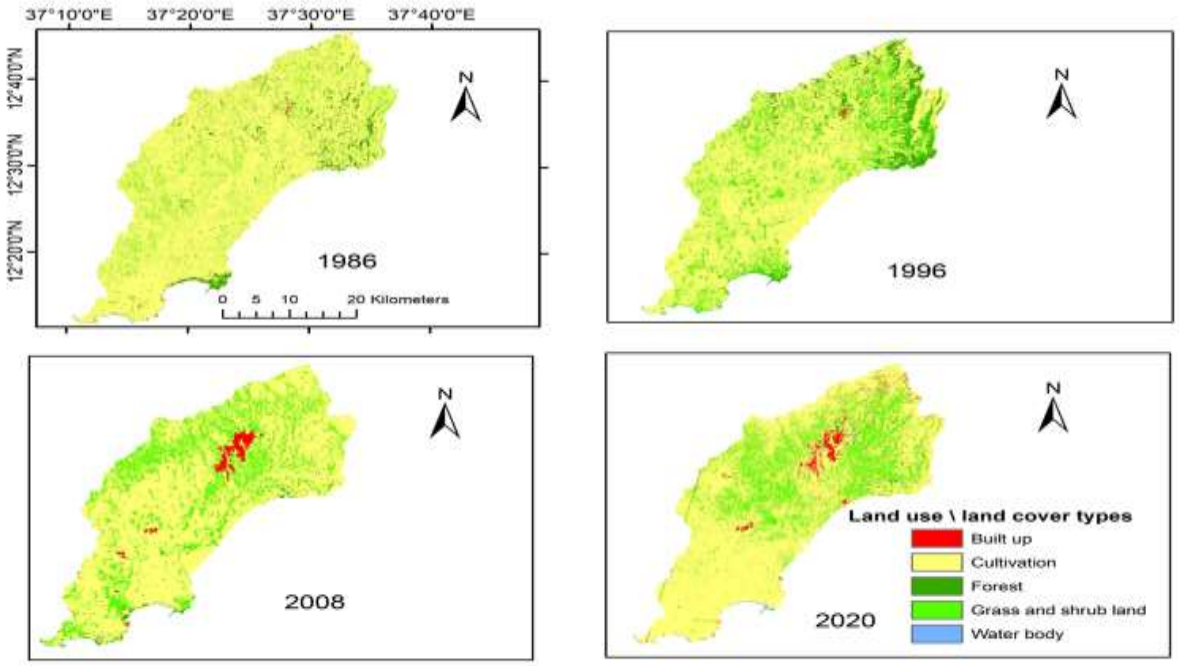

Fig. 4: Classified LULC Maps of 1986, 1996, 2008, and 2020 for the Megech watershed

CHAPTER SEVEN

7.1 Farmers' perception on watershed degradation, involvement in watershed management and factors influencing management practices: The case of Megech watershed, northwest Ethiopia:

In the highlands of Ethiopia, in particular, watershed degradation has become a significant environmental hazard. This research assessed farmers' perceptions of the causes, consequences, and control mechanisms of watershed degradation and factors influencing the farming community's involvement in watershed management. A sample of 371 farmer households was studied using multistage, simple random, and proportional sampling techniques to accomplish the study. The data was collected using a survey questionnaire, field observation, and key informant interviews. Descriptive statistics and a binary logistic regression model were the data analysis methods. Excel and SPSS software 23 were data analysis tools.

Deforestation, overgrazing, population growth, poor land management, and crop residue mishandling are the primary drivers of watershed degradation in the Megech watershed. Farmers were aware of the consequences of watershed degradation, such as a decline in crop yield, soil fertility loss, and vegetation and wildlife loss. Farmland size reduction, rise in the cost of production, forage access problems, limited water access, food insecurity, and climate change are perceived consequences. Regarding land ownership, 51.2% of the farmers perceived the government as the landowner. 87.1 percent of farmers agreed on the significance of watershed conservation. Farmers' involvement in watershed management was affected by family size, landform type, soil erosion extent, extension service, access to soil and water conservation facilities, training exposure, participation in different social activities, and distance from the farm plot.

The binary logistic regression showed that these factors were statistically significant at $P<0.05$. However, farmers' sex, age, educational status, marital status, land ownership, and ownership certification were not statistically significant at $P< 0.05$. Terracing, ditch work, and cut-off drains were the most common methods used by farmers, along with some waterway, Fanyajju, and soil bund construction. Increasing farmers' understanding of environmental degradation problems and management alternatives is crucial. Preparing and applying

contextualized watershed management rules is also beneficial. Enhancing watershed conservation practices through a bottom-up approach would be essential. Empowering farmer associations and watershed development committees and showing farmers how to be benefited through long-term natural resource protection is beneficial for sustainable management of the watershed.

CHAPTER EIGHT

8.1 Summary and Conclusion:

It is possible to map the terrain, analyze land use\land cover change, and quantify soil erosion extent using remote sensing and geographic information system, to manage the Megech watershed in an integrated approach. The digital elevation model analysis indicates that the watershed has a surface area of 1309.56 km^2. The prominent landform of the Megech watershed is low mountains (31.53%), irregular plains (28.18%), smooth plains, flat landforms (19.16%), and breaks (14.86%). The slope classes are 0–10 degrees (62.65%), gentle slope, 15 25 degrees (25.19%), moderate slope, and >45 degrees steep slope, covering 4.14% of the watershed. The north, northwest, and northeast are the most vertical terrain, greater than 45 degrees, reaching 75 degrees and showing very steep terrain.

The geological elements include basalt, alluvium, colluvium, and marsh soils. The terrain wetness index of 5.71 occurs in locations with more extensive upslope areas drained to a gentler slope of the watershed near Lake Tana. The shape of the watersheds reveals the elongated shape and the dendritic pattern. The watershed includes a third-order stream. Lower stream orders, in particular first-order streams, dominate the sub-watersheds. The topographic ruggedness index results indicate that the southern portion of the watershed is nearly level. In contrast, the northern and northeastern parts are rugged terrain, which could be susceptible to soil erosion. Based on stream power index analysis, the upper part of the Megech watershed, especially the north and northwest parts, is the source of many streams flowing to the south, where erosion could occur.

Eutric Leptosols (46.45%), Eutric Vertisols (44.03%), and Chromic Luvisols (7.75%) were significant soil types in the Megech watershed. Clay soils cover 57.83% and clay to clay loam 41.43%, which are the important textures. The RUSLE model shows the mean annual soil loss is 110.60 t ha^{-1} yr^{-1}. Each year, a total of 8499.74 t $h^{-1}yr^{-1}$ of soil eroded. On average resulting in 1605.30 t/km^2/year, sediment material has been transported to the stream channels and deposited with a sediment delivery ratio of 1.87. The strength of soil erosion in the area is divided into six categories. The erosion rate classes were 46.38 percent (0-12 t ha^{-1} yr^{-1}) low, 13.63 percent (12-20 ha^{-1} yr^{-1}) moderate, 9.22 percent (20-35 ha^{-1} yr^{-1}) high, 12.30 percent (35-

50 ha^{-1} yr^{-1}) very high, 7.20 percent (50 up to100 ha^{-1} yr^{-1}) sever, and 11.27 percent (>100 ha^{-1} yr^{-1}) very severe erosion.

The land use\land cover change analysis from 1986 to 2020 showed that forest land change was 2.09% from 1986 to 1996. From 1986 to 2020, it changed and declined by -4.68%, with a continuous decreasing trend in the study area from 1986 to 2020. The shrubland has changed by 13.93% from 1986 to 1996; from 1996 to 2020, it increased by 0.96%. From 2008 up to 2020, it decreased by -1.92%. Generally, from 1986 to 2020, it was altered by 12.90%, indicating an increase. The cultivation land increased and expanded from 1996 up to 2020. The built-up area changed continuously from 1986 to 1996 by 0.44%.

Deforestation, overgrazing, population growth, poor land management, and crop residue mishandling are the primary drivers of watershed degradation in the Megech watershed. Farmers were aware of the consequences of watershed degradation, such as a decline in crop yield, soil fertility loss, and vegetation and wildlife loss. Farmland size reduction, rise in the cost of production, forage access problems, limited water access, food insecurity, and climate change are perceived consequences. The binary logistic regression showed that these factors were statistically significant at $P<0.05$. However, farmers' sex, age, educational status, marital status, land ownership, and ownership certification were not statistically significant at $P< 0.05$. Terracing, ditch work, and cut-off drains were the most common methods used by farmers, along with some waterway, Fanyajju, and soil bund construction.

Finally, based on this research, it is recommended that:

- The ruggedness number for the Megech sub-basin was 0.56, indicating moderate and long, rugged topography for the Megech River, which could be susceptible to soil erosion and flash flood characteristics. The land use\land cover change analysis also showed that forest resource has declined from time to time. Hence to reverse the problem, intensive afforestation is required.
- Annual soil erosion of 110 tons of ha^{-1} per y^{-1} in the watershed is very high. Hence, physical and biological watershed conservation measures such as hillside terracing, soil

bund structure, tree planting, and degraded area closure need to be strengthened for rehabilitation.

- Urban expansion at the expense of cultivated land should be carefully planned.
- Increasing farmers' understanding of environmental issues and management alternatives is crucial.
- Applying contextualized watershed management guidelines based on a bottom-up approach is also beneficial.
- Enhancing watershed management methods by empowering farmer associations and local government institutions would benefit long-term resource protection.

List of Publications:

Papers Published in International Journals:

1. Habtu, W., & Katihally, J. (2023). Terrain mapping and analysis for land management: the case of Megech - Dirma watershed, sub-basin of the Blue Nile basin, Northwest Ethiopia. Arabian Journal of Geosciences,16, 1–27. https://doi.org/10.1007/s12517-022-11110-5
2. Worku Habtu and Jayappa. (2022). Assessment of soil erosion extent using RUSLE model integrated with GIS and RS: the case of Megech - Dirma watershed, Northwest Ethiopia. Environmental Monitoring and Assessment, 1–25. https://doi.org/10.1007/s10661-022-09965-y
3. Habtu, W., & Jayappa, K. S. (2021). Use of ASTER DEM data for Morphometric Analysis of Megech-Dirma Watersheds, Blue Nile Basin , Ethiopia : Implications for Soil and Water Conservation. Remote Sensing of Land, 5(1), 27–40.

Papers communicated:

1. Worku Habtu and Jayappa, K. S. (2022). Farmers' perception on watershed degradation, involvement in watershed management and factors influencing management practices: The case of Megech watershed, northwest Ethiopia. Submitted to Journal of mining and degraded land management.
2. Worku Habtu and Jayappa. K. S. (2022). Investigation of land use\land cover change and potential drivers: the case of Megech watershed, Blue Nile basin, northwest Ethiopia.

Presentations at National and International Conferences:

1. Worku Habtu and Jayappa. K. S. (2022). Farmers' perception on watershed degradation, involvement in watershed management and factors influencing management practices: The case of Megech watershed, northwest Ethiopia. Submitted to Journal of mining and degraded land management. 2nd international conference on environment, socio-economic, and health impacts of degraded and mining lands. August 30th - 31st, 2022. Soil department, faculty of Agriculture, Brawijaya University, Indonesia.
2. Worku Habtu and Jayappa. (2021). Participated and presented a paper entitled "Terrain Mapping and Analysis for Land Management: the case of Megech watershed of the Blue Nile basin, northwest Ethiopia," in the Eurasian Conference on Science, Engineering & Technological Innovations: November 20 & 21, 2021. (Online mode) Jointly organized by Kryvyi Rih National University, Ukraine, Europe Automation, Computer Science and Technology Department Research Culture Society & Co-Sponsored by Scientific Research Association. Ref. No: RCS/ECSETI-21/CPP/004
3. Worku Habtu and Jayappa K. S .(2021). Online poster presentation entitled "Estimation of Soil Erosion Extent using RUSLE Model Integrated with GIS And RS: The Case of Megech Watershed of The Blue Nile Basin, northwest Ethiopia" on "GIS DAY CELEBRATION-2K21", Organized by Department of Civil Engineering and Centre for Data Science and Machine Learning in association with, ESRI, Pvt. Ltd held at Centurion University of Technology & Management, Odisha, India, November 17th, 2021.

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